

Methodology of land degradation mapping applied to mountain areas: case of the Mebtouh River Watershed - Béni Chougrane (Algeria)

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ABSTRACT

Water erosion is a very serious phenomenon in Algeria that has a severe impact on the land heritage. It affects 45% of the tellien areas or 12 million hectares of cultivable land. This phenomenon becomes even more serious if we know that 85% of cropland is located in the areas most susceptible to erosion. Analysis of erosion processes is of considerable interest in optimal and sustainable land use. It is to highlight soil erosion processes with a view to implementing for the identification and understanding of the current dynamics of watershed weathering and its perverse effects on the sustainable development of our territories.

The proposed approach involves modelling certain key parameters, including precipitation aggression, soil erosion, slope tilting, vegetation cover and anthropogenic action to combat this phenomenon. The Universal Soil Loss Equation (USLE) model was chosen to quantify and spatialize water erosion processes.

The objective of this study is to develop a methodology for understanding the hydrodynamic behaviour of water and soils in general and monitoring the progression of this insidious phenomenon at a watershed area. To do this, we used a mapping game using a geographic information system (GIS) for a pilot site is the Mebtouh River watershed (north-west Algeria). The approach is to highlight soil structure, land use and water transfers and their effects on soil degradation.

Keywords: Water erosion, mapping, soil degradation, GIS, Mebtouh River.

Mathematics Subject Classification: 92F05, 30C30, 65E05

Journal of Economic Literature (JEL) Classification: General and reference~Estimation

1. INTRODUCTION

In northern Algeria, the phenomenon of water erosion presents the form of very serious physical degradation of soils affecting the relief and the economy of the country. This phenomenon is linked to

the context of the use of natural resources beyond their capacity for restoration, often aggravated by fluctuations in climatic and anthropic conditions.

This natural hazard particularly affects mountain ranges, where nearly 2000 tons / km² / year of sediments are torn from watersheds and 120 million tons of sediment annually join Dam reservoirs (Anis, 1991), leading to a decline in agricultural production, rooting the local population in poverty.

To track the progress of this insidious phenomenon, space tools, such as remote sensing and geographic information systems (GIS), seem to be favored. They allow a multicriteria analysis of the water erosion process based on the USLE empirical equation, namely, the parameters of soil erodibility, topography, land use, erosivity of rainfall, cropping practices erosion control.

In this sense, several studies have been devoted to understanding and predicting water erosion processes in Mediterranean landscapes (Clark, 1999). The objective of this study is to develop a methodological approach based on ecological indicators highlighting the transformations of the environment, in order to develop accurate maps, allowing the monitoring of the progression of this degradation and its management.

2. MATERIAL AND METHOD

2.1. Study Area Location

The pilot site selected corresponds to the Mebtouh River watershed, located in the Béni Chougrane Mountains (north-western Algeria). It covers an area of approximately 637.86 km². It is part of the Mactaa watershed, flowing north into the Mediterranean (Figure 1).

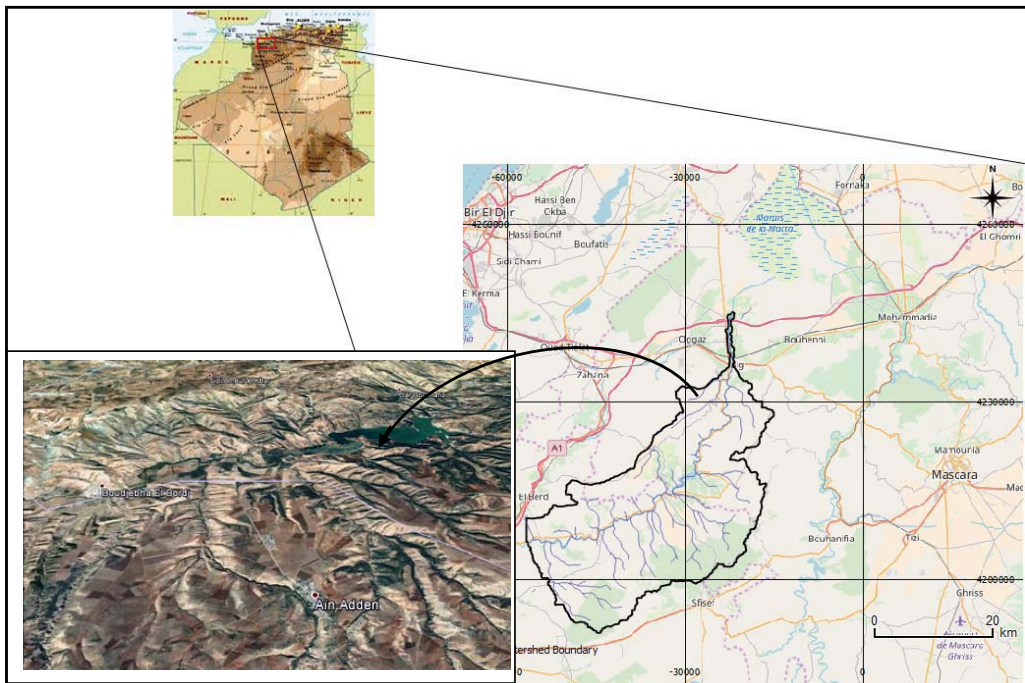


Figure 1. Location of experimental site / Mebtouh Watershed River

The geological structure is very monotonous with an alluvial plain, bounded by the clay stones of the Upper Pliocene, gypsum and clays of Upper Miocene. Aquifer formations along Mebtouh are intermittent with a tendency to drain after precipitation. In general, free aquifers have transmissivity (T) ranging from -10^{-3} to -10^{-4} m²/s. Surface water supplies are estimated at 4.42 Hm³/year.

Morphologically, our pilot area is characterized by rugged terrain with a high sensitivity to water erosion. The main watercourse originates in the south in the Sidi Bel abbes plateau and then takes a North-north-western direction to begin crossing the Beni Chougrane mountainous terrain (Figures 2 and 3).

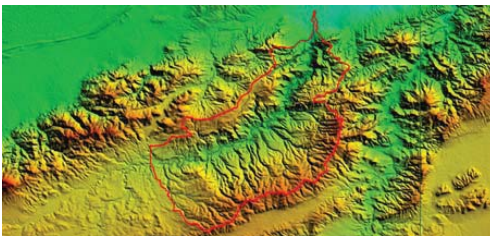


Figure 2. Topographic section of the watershed

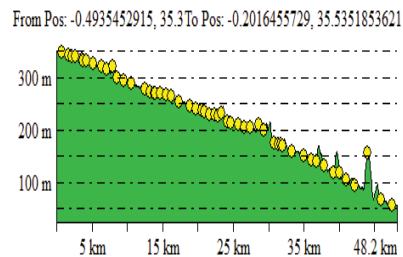


Figure 3. Watercourse Profile

At the climate level, the region is recorded by rainfall, characterized by a semi-arid regime, leading to an irregular distribution of rainfall in space and time. The rainy season generally runs from December to March, ranging from 400 to 500 mm/year.

The lithological structure is characterized by the predominance of a coarse, or frankly soft, argilo-marneuse soil structure.

The effects of coaling are increasing in the South west to North-east, aided by aggressive rainfall, low vegetation cover and unsuitable anthropogenic activities on high-gradient land.

The speculative agrarian conquests have multiplied in recent years in need, which has significantly influenced changes in the mountainous environment and its environmental components, resulting in the rapid siltation of the downstream Cheurfa Dam reservoir.

Given the magnitude of such a phenomenon in terms of ecology (loss of indigenous soil-fixing plant species), economics (weakening of productive performance), and water (water scarcity), experimental research is urgently needed (Figures 4).

This is the case with our study area, where the risk of rapid siltation of the Cheurfa Dam (Figures 5), requires intervention through an integrated approach to assessing the dynamics in our watersheds using scientific tools that have been widely demonstrated to be effective across the Mediterranean basin.



Figure 4. Morphology and land use



Figure 5. Cheurfa Dam retention

2.2. METHODOLOGIES

The methodology adopted involves the integration and representation of mapping and descriptive data on natural environment components in a geographic information system (GIS) to analyses soil erosive behaviour. To achieve this, we have:

- Land use mapping using remote sensing data;
- Application of GIS for water erosion assessment and mapping;
- The study of soil infiltration capacity and its relationship to the erosion process.

For example, we have created a spatially referenced database of qualitative and quantitative information from the study watershed, the synoptic pattern of which is shown below (Figure 6).

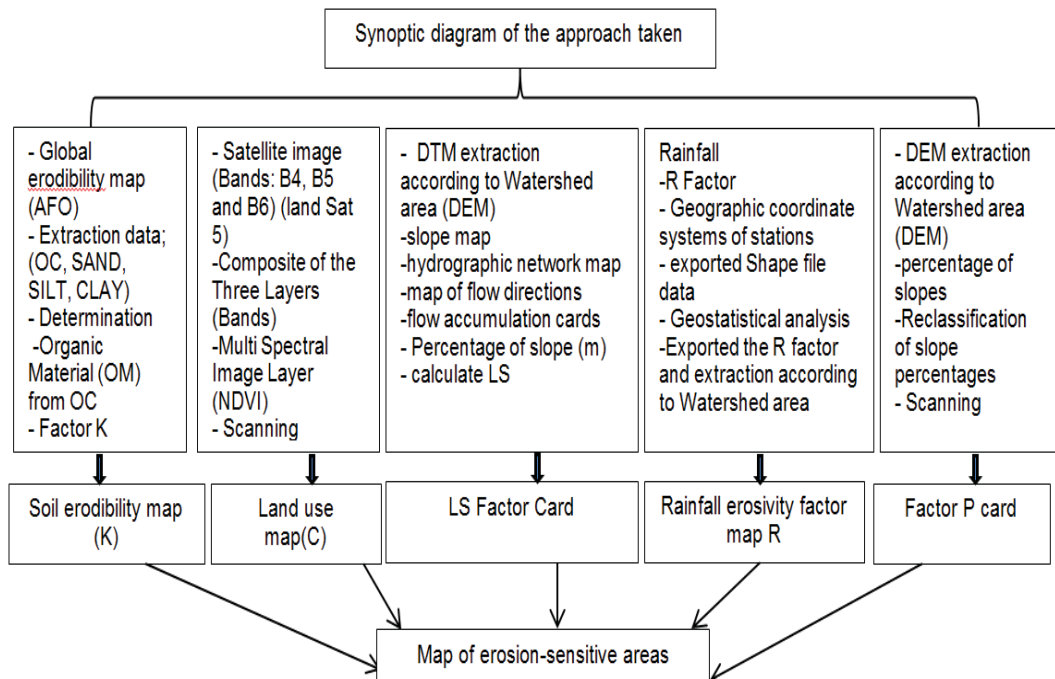


Figure 6. Synoptic diagram of approach taken

2.2.1. Baseline data used

The dataset consists of satellite imagery by Landsat's TM and ETM+ sensor, acquired on 16/03/2017, an digital terrain model (DTM) and meteorological and soil field measurements. These images are georeferenced according to the conforming conical projection of WGS_1984_UTM_zone_30 N (Northern Algerian System) to allow for geometric preprocessing and integration of satellite images into the GIS.

The development of the land use map is done through a combined process that involves two phases, an image-interpretation followed by a classification led by maximum likelihood. Themes are defined based on soil characteristics, vegetation and agricultural use of reference plots observed in the field.

2.2.2. Erosion Mapping Parameters

Modelling of the water erosion process in the study area was done using the Universal Soil Loss Equation (USLE) in its adapted version by Kalman (1967). This model combines five factors affecting the severity of erosion and is presented as follows:

$$A = R \cdot K \cdot LS \cdot C \cdot P$$

With:

- A = soil loss rate (t/ha/year),
- R = rain erosion,
- K = soil erosion,
- LS = topographic factor integrating slope and length of slope,
- C = soil protection factor by vegetation cover,
- P = factor expressing soil protection by agricultural practices.

A) LS Topographic Factor

The LS factor is calculated from the *Shuttle Radar Topography Mission (SRTM)* which requires several pretreatments in a raster form (*Geo TIFF Tagged Image Files Format*) to inform each 90-metre pixel of altimeter (Z).

For a question of precision several steps, using the spatial analysis functions are followed. The first is the creation of a flow direction shaver from each cell to its neighbour at lower altitude.

This theoretical flow accumulative hydrographic flow then calculates the slope length for one cell and then for each cell. The second step is to calculate the slopes in degrees for each cell. Thus, the value of the exponent m varies according to the gradient of the dominant slope in the study area (Table 1).

Table 1: Change in m-value based on degree of slope in %

m value	Slope %
0.5	> 5
0.4	3-5
0.3	1-3
0.2	< 1

In our case, the LS map is based on mathematical algorithms, obtained by using the following formula:

$$LS = \left(\text{flow accumulation} \cdot \frac{\text{resolution}}{22.1} \right)^{0.5} \cdot (0.065 + 0.045s + 0.006s^2)$$

With s : degree (gradient) of the slope in %.

The slope map shows that the percentage of dominant slopes in our study area and 3-5% where m value is 0.4

B) Factor of Vegetal coverage C

It is widely accepted that the risk of erosion increases inversely to soil cover or other residues, allowing protection from heavy rainfall and sporadic run-off (Bannari et al. 1999). Today, C-factor is easily obtained by the input of geomatics, by calculating the vegetation index (NDVI) from a classification of Landsat images. This type of map is used to derive the soil protection factor by vegetation cover (factor C).

C) Soil Erdibility Index: (K)

Representing the erodibility coefficient of a watershed, this factor is extracted from soil data provided by the Food and Agriculture Organization (FAO) on its HWSD site. Once extracted, the organic matter (OM) and organic carbon (OC) are assessed using the formula:

$$OM = 1.72 \cdot OC$$

Erdibility (K) is assigned for each soil type based on soil texture (sand, silt, organic matter). In our case, the value of K is 0.34.

D) Rainfall erosivity factors (R)

The evaluation of the R-Index is based on the formula of Wiscschmeier and Smith (1978) by correlating annual and monthly precipitation:

$$R = 0.074 \cdot F^{1.49}$$

With:

- R = rain and run-off factor (10-2 N h¹/year) [N is Newton force]
- F = fournier (1960) index (mm)

$$F = \sum_{i=1}^{12} P_i^2 / P$$

With:

- P_i : monthly precipitation (mm)
- P: annual precipitation (mm)

Rainfall data is derived from CFSR weather data (*Climate Forecast System reanalysis*). Thirteen (13) stations were selected for precipitation measurement and R-factor determination.

E) Factor (P)

The approach developed for P-calculations is defined as the ratio of soil loss to the corresponding soil loss-specific anti erosive practices with straight-line tillage and downward tillage. In the absence of measurable data on soil anti erosive practices on the Mebtouh River watershed and given that only 10% is used for grain crops and cropping fields, the factor (P) is estimated based on the crop bypass/slope relationship (Shin 1999).

2.2.3. Protocol Analysis

The USLE model is based on a linear function involving the spatial combination of different factors contributing to soil erosion (C, P, LS, R, K). The shaving mode is particularly suitable for multi-factor analysis and representation of continuous data such as soil nature and land use (collet, 1992).

Indeed, as soon as one is interested in analytical models, the shaving mode is widely preferred to ensure geometric properties common to all layers of information. Spatial analysis and modelling are facilitated by a simple data structure and regular grid form (Donnay and Binard, 1991).

Similarly, the cross-over of multilayer data is facilitated because all sizes are brought to the same basic unit, the pixel. The combination of layers is based on arithmetic rules and Boolean operators to produce a new value in the composite layer, representative for each soil loss pixel (A).

3. RESULTS AND DISCUSSION

The results result, on the one hand, in the calculation of the different factors in the USLE equation and on the other, in their spatialization. The estimate of potential soil losses is emitted (A) highlight the erosive potential of Mebtouh River watershed. They provide an estimate of the soil losses potentially provided by each mesh, which is suitable to discuss the choice of equations used and the relevance of the results at the pilot level.

3.1. Calculating the Rainfall Erosive Factor (R)

Using the Climate Forecast System reanalysis (CFSR) *model* for calculating the rainfall erosion factor (R) resulted in an overall assessment of rainfall aggressiveness in the study area. Because sub-basins are poorly instrumented and large, these climate interpolation data (local, global) allow the role of precipitation in modelling soil erosion. The distribution of precipitation by altitude shows an increasingly tiered R-factor. Thus, rainfall erosion naturally increases downstream of the watershed (Figure 7).

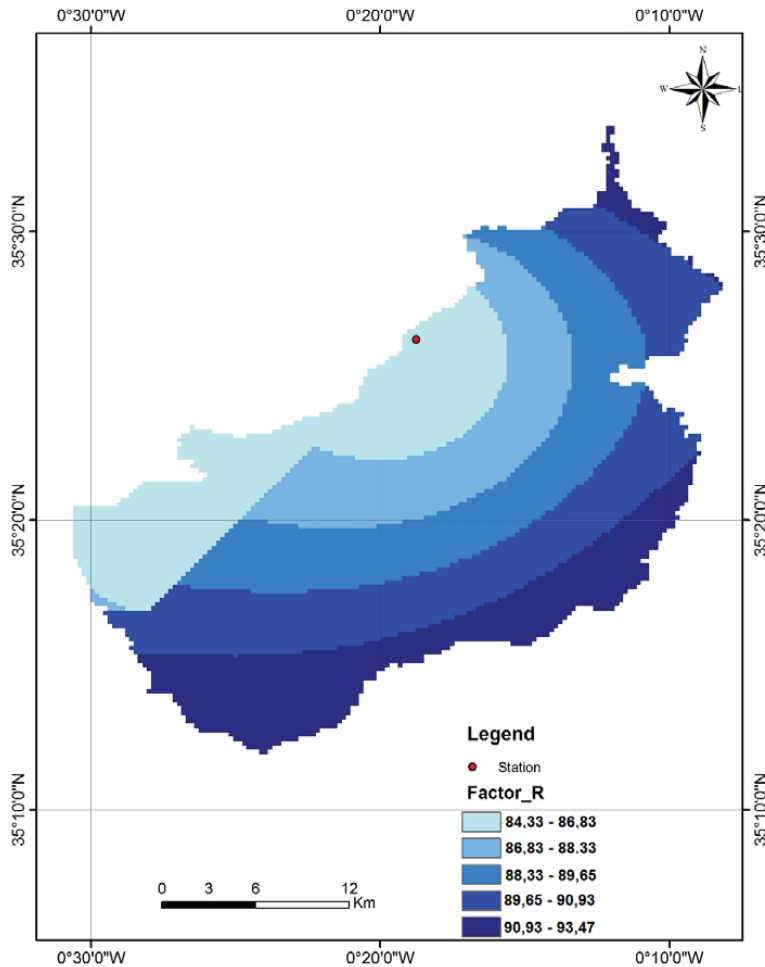


Figure 7. Factors in rainfall erosion R

The R values range from 84.37 to 93.47 with an average of 88.92. For 80% of the surface of the Mabtough watershed, the R values are greater than 86.83. In comparison, the R factor calculated from the regression equation between the annual average of precipitation below 850 mm and the erosivity of rainfall estimates an error of 10 to 15% (Renard and Freimund 1993).

Other authors, having applied the USLE equations to calculate R based on annual precipitation and the Fournier index, showed similar results (Morschel and Fox 2004; Sadiki and al., 2004).

3.2. LS Topography

Naturally, low slopes are not sensitive to the erosion process, while the steep upwind landforms reveal greater sensitivity to erosive processes. This is shown by the low LS topographic factor values ranging from 0 to 14.16 attributed to the plains and bed of Mebtouh River. In contrast, the high values of LS (>14.16) correspond to the steep slopes (Figure 8).

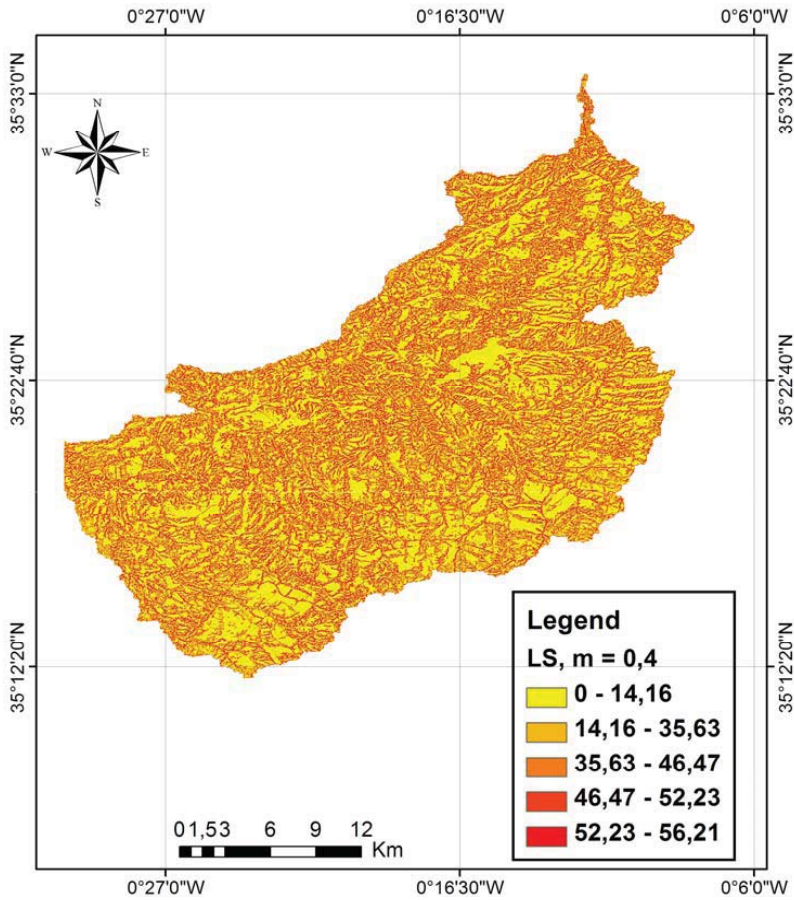


Figure 8. LS Factor of Mabtough Watershed

The results are more satisfactory than the actual topography of the watershed, which has an average slope of less than 7% and an estimated maximum slope length of 230 m. The work of Kirchner and Guth (2010) shows that values calculated from digital terrain model (DTM) (ASTER/SRTM) are more important than those measured in the field. This is attributed to the smoothing of surfaces and the disappearance of micro reliefs.

Extreme values (minimum and maximum) are generally greater than those actually observed. For example, the extent of slope values ranges from 6% to 41% for data acquired in the field and ranges from 0.32% to 45% for MTRS data in the Himalaya (Datta and Schack Kirchner, 2010).

3.3. Anti-erosive Practices (P)

The operation of the last General Census of Agriculture (RCA) indicates a 15% afforestation rate for our study area in the Mabtough watershed, with the remainder for cereal crops and market gardening. Highly vegetated, spiny forest-type areas are associated with the lowest coefficient (0.55), and the highest coefficients (0.89 to 1) are for bare soils (Figure 9).

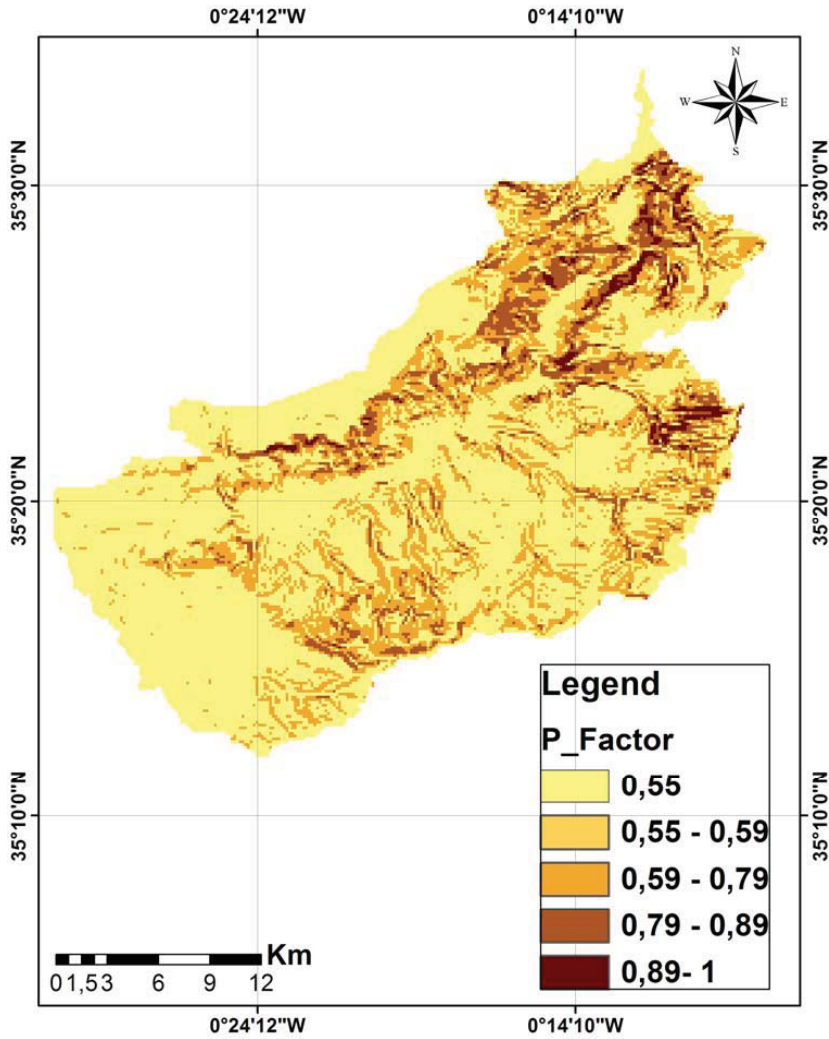


Figure 9. Soils Represented on the Mabtough Watershed

3.4. Land Occupancy C

The data available to account for factor C is a fairly reliable means, which induces a large variability in the erosive process depending on the types of land use. High erosion sensitivities are associated with the extensive presence of degraded herbaceous secondary plant formations and annual cropping areas. Bare soils are the type of soil occupancy most susceptible to erosion. For example, in urban areas, run-off rates increase with decreased infiltration, which influences the rate of erosion (Figure 10).

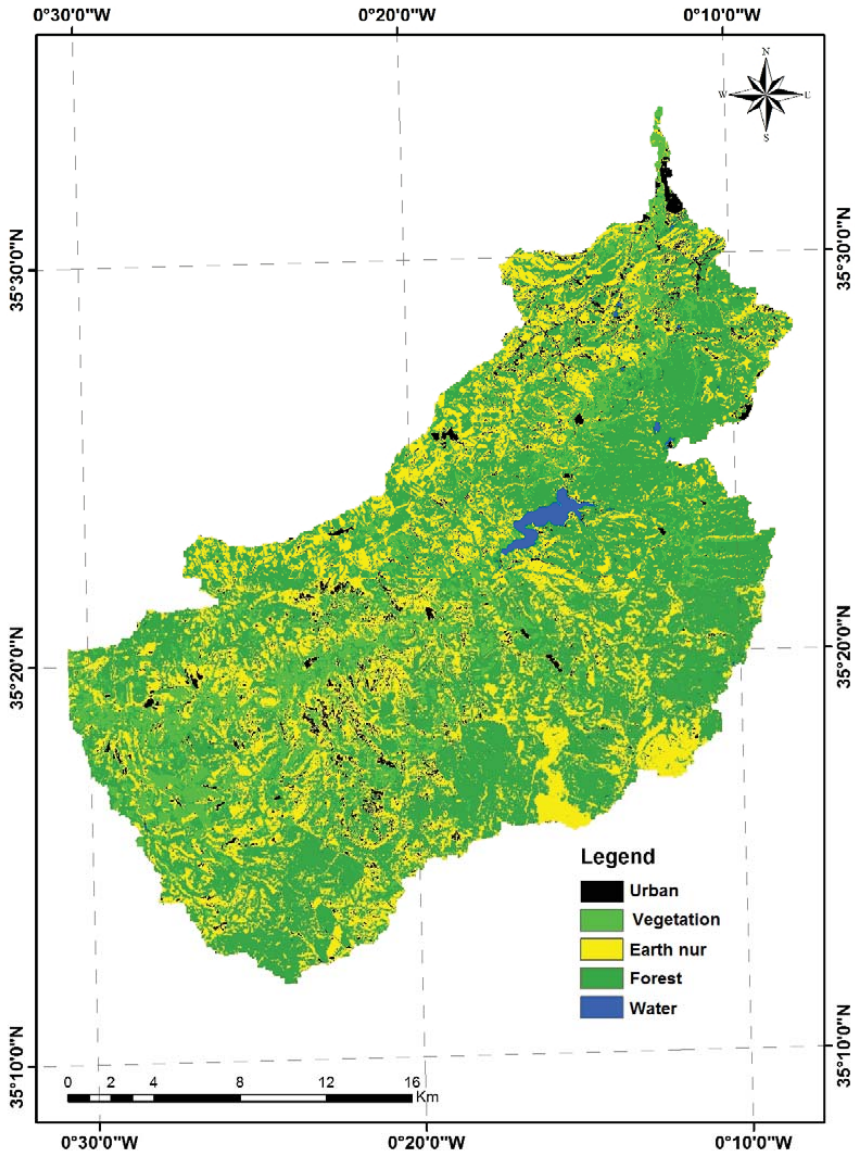


Figure 10. Soils occupancy (C) in the years 2017 of Mabtouh Watershed (Landsat 5)

3.5. Soil Erodibility K

Correspondence between soil texture and soil erosion has highlighted the most erodible soils in the watershed. K factor is estimated at 0.34 for almost the entire watershed, which is considered sensitive soils (Figure 11). The most erodible soils are lithosols and ferruginous soils.

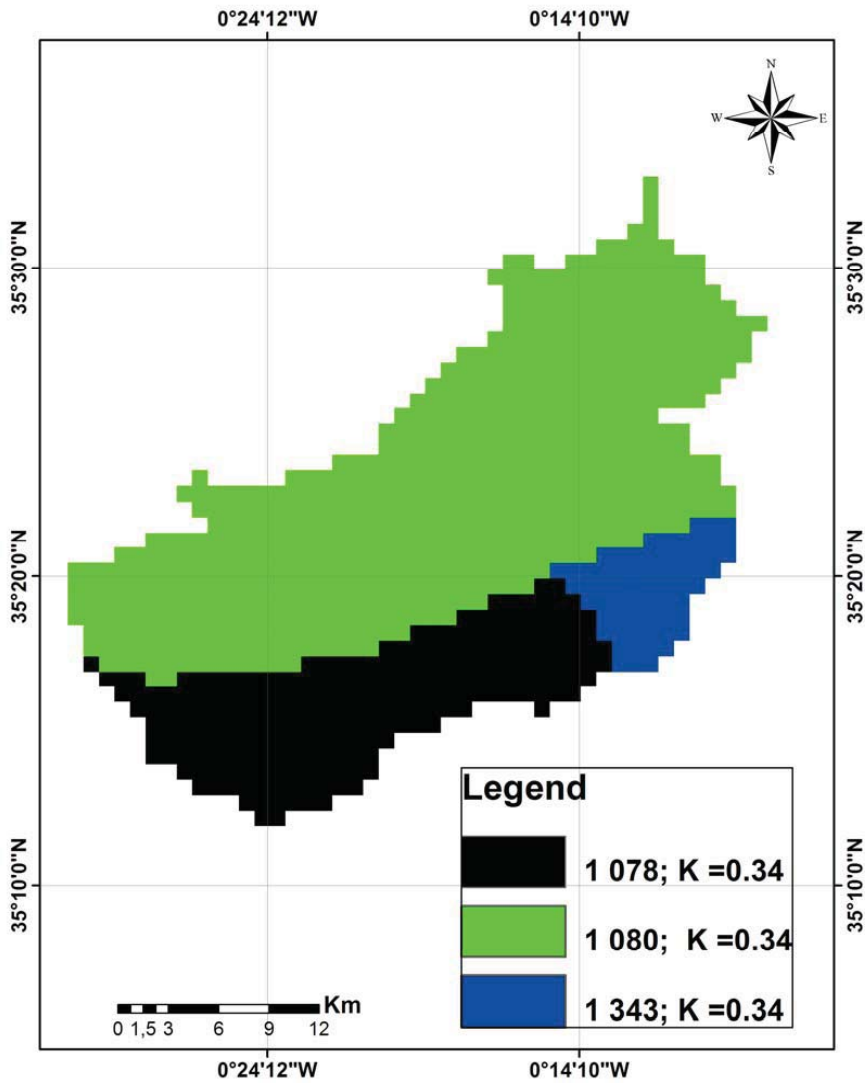


Figure 11. Soils Erodibility (K)

3.6. Estimating soil losses

Results from this study highlight the erosion dynamics of the Mebtouh River watershed. The soil loss map shows that soil loss values range from 0 to 997119, depending on the watershed area (Figure 12). The average soil loss is estimated at 377 341, which is considered high.

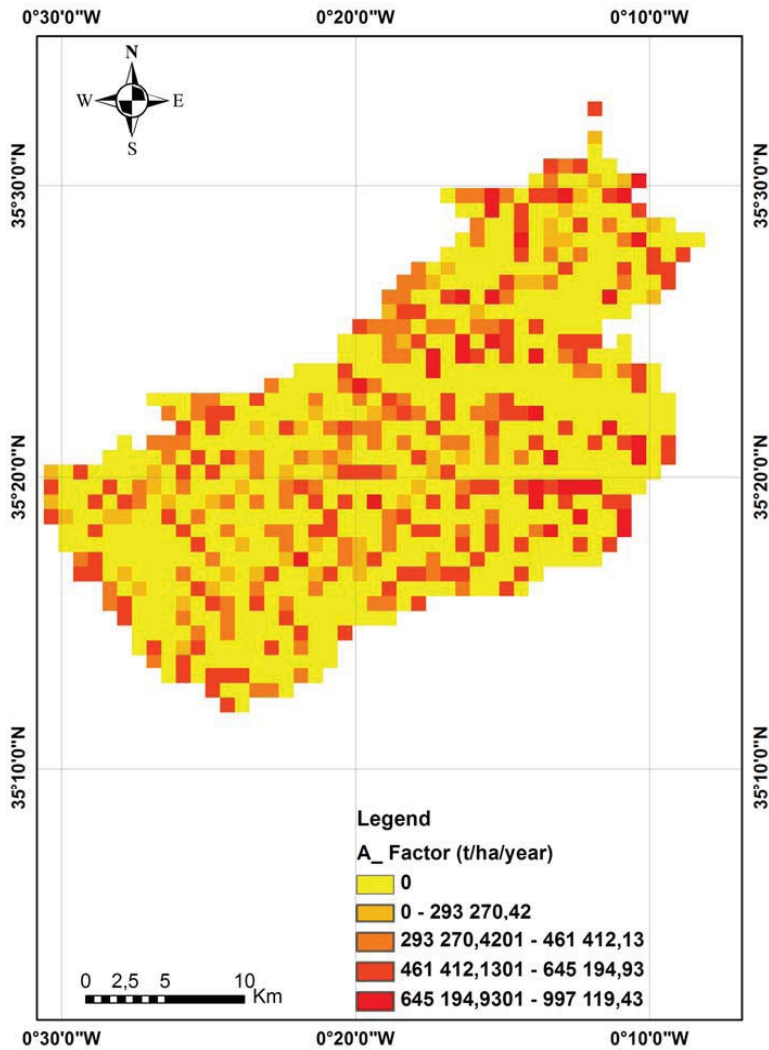


Figure 12. Estimated Soils Loss of Mabrouh Watershed

In our case, the most sensitive areas are 20 km² and can release up to 997119 materials. At the watershed level, 2396897 tons/year of material can potentially be torn off and thus contribute to the erosive dynamics of this mountain area.

This estimate shows that 68% of the Mabrouh watershed area shows low to moderate susceptibility to erosion (Table 2) while 15% are exposed to very high sensitivity (greater than 293 270.4 t/year).

Table 2: Erosion Sensitivity of Surfaces (km²)

Total area	Low to moderate	Medium	Raised	Very High
621	423	93	85	20
100 %	68 %	15 %	14 %	3 %

In addition, soil losses associated with degraded cover and deforestation it should be added that increasing anthropogenic pressure on ecosystems plays a negative role due to the lack of broader awareness, particularly in terms of information on erosive processes at the watershed level.

Indeed, the dynamics of land-use change and surface states are often rapid, driven by ranching and poor cropping practices on sloping land.

The application of these soil loss equations and the validation of the model are done in comparison to the results of the bathymetric survey at the outlet of the Cheurfa Dam (ANBT 2003). The latter shows that the amount of siltation reached a volume of 9.79 Hm³ within ten (10) years. In other words, the carrying volume of the drainage basin is 1566400 tons/year, or 34.64% siltation.

This enormous amount of material deposited at the Dam retention confirms the model's results and perfectly justifies the estimates of the erosive parameters studied, in particular the K factor, expressing the erodibility of the nature of the soil in these watersheds with weakened texture due to the combined effects of nature and man.

4. CONCLUSION

Satellite information has proven to be fundamental for assessing and mapping surface states with respect to water erosion. It offers the possibility of identifying, locating and classifying large sets of land use and occupancy in order to map them.

Risk mapping, especially of areas with higher erosion rates, facilitates intervention decisions and the choice and planning of conservation measures.

Results of this approach combining remote sensing and GIS have led to erosion mapping highlight the importance of soil structure, land-use type, land-use pattern and types of land use soil on water transfers and the consequences for soil loss.

Soil loss estimates given by the USLE model show a good correlation with the type of land use, the land use method, the geological formations and more specifically the soil types.

Finally, although the marly lithology of Mabtouh River watershed suggests a high sensitivity to water erosion, the erosive action is even more accentuated than when the soil is fallow or rangeland and unprotected by a blanket vegetable.

These results suggest some recommendations and proposals that can improve the drainage and infiltration quality of the different units of the Mabtouh River watershed for the fight against the erosion of its lands, notably:

- Encourage population to practice arboriculture, especially on steep slopes, which offers the possibility of soil and water conservation;
- To make the population aware of inappropriate methods of exploitation (plowing in the direction of the slope);

- To implement a sylvo-pastoral development aimed at increasing the forage production of pastoral species, in order to better manage pastoral exploitation in the region.

Although the method used is based on a qualitative approach, its relevance has been justified during several works in Mediterranean regions. It is, however, destined to evolve thanks to the continuation of experiments which will allow a better characterization of the diagnostic criteria. In addition, to improve the results of this study, we formulate the following research perspectives:

- Other similar studies must be done but with the rain simulator which gives results close to reality;
- Take into account gully erosion and try to integrate it into an overall soil loss model;
- Take measurements at the plot scale and study the phenomenon in its natural landscape and watershed context, to better identify the nature of the risks associated with runoff and recommend a solution adapted to the problem.

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